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# **Exploring the abstractness of number retrieval cues in the computation of subject-verb agreement in comprehension**

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## Abstract

Subject-verb agreement has provided critical insights into the cue-based memory retrieval system that supports language comprehension, by showing that memory interference can cause erroneous agreement with non-subjects: ‘agreement attraction’. Here we ask how faithful retrieval cues are in relation to the grammar. Are retrieval cues as abstract as the terms in which the grammatical dependency is stated, or are they sometimes more specific, targeting only certain instantiations of an abstract category? Previous work cannot distinguish whether the number retrieval cue of the verb is targeting an abstract category like [plural], or an unequivocal exponent of the abstract category (‘-s’). The current set of studies aims to resolve this question, and also to ask whether retrieval may even target imperfect correlates of syntactic plurality in environments where they do not grammatically license agreement. We examine the impact of conjoined singular attractors (*The advice from the doctor and the nurse...*), which are syntactically plural, but whose plurality is introduced by a vehicle, the conjunction ‘and’, that is not an unequivocal correlate of syntactic plurality. We find strong agreement attraction, which suggests that retrieval processes do not only target unequivocal morphological correlates of syntactic plurality. However, we also find evidence of moderate attraction with conjoined adjective attractors (*The advice from the diligent and compassionate doctor...*), which is compatible with a system in which an imperfect correlate of syntactic plurality, like the word ‘and’, can become associated with the plural retrieval cue due to frequent co-occurrence with the actual target feature.

## **Keywords**

Agreement, sentence processing, memory retrieval, interference

## **Highlights**

Memory interference can cause erroneous agreement checking with non-subjects (‘attraction’)

We used self-paced reading and speeded acceptability judgments to investigate the abstractness of the number retrieval cue in subject-verb agreement processing in comprehension

Conjoined singular attractors (*The advice from the doctor and the nurse*), which are syntactically plural but do not contain an unequivocal correlate of syntactic plurality, cause strong attraction effects

The vehicle by which the feature licensing agreement in the grammar is introduced does not have an impact on whether it is targeted by the number retrieval cue in memory

## Introduction

Understanding sentences requires comprehenders to establish dependencies between linguistic items that may not be directly adjacent to each other. For example, in the sentence ‘*The boy next to the beautiful trees probably does not hear the music*’, the verb ‘*does*’ has to agree in number with the subject phrase, despite being separated from it by an adverb, and even though many words intervene between the verb and the head of the subject, ‘*boy*’, which contains the number information. Recent research has used a number of linguistic dependencies to investigate the architecture of the memory system underlying this process, and has suggested that it relies on cue-based retrieval of content-addressable items in memory (Wagers, Lau & Phillips, 2009; Tanner, Nicol & Brehm, 2014; Dillon, Mishler, Sloggett & Phillips, 2013; Lago, Shalom, Sigman, Lau & Phillips, 2015). Here we ask how faithful retrieval is in relation to the grammar. Are retrieval cues always as abstract as the terms in which the grammatical dependencies are stated? Or are they sometimes more specific, targeting only certain instantiations of an abstract category, perhaps the most frequent ones? Recent findings from Arabic suggest that retrieval might target only specific instantiations of an abstract category (Tucker, Idrissi & Almeida, 2015). In this paper we pursue the issue through subject-verb agreement in English, aiming at the general question of how the grammar is respected in processing (Lewis & Phillips, 2015).

### *Cue-based retrieval in sentence processing*

Much recent work on sentence processing supports the view that the underlying memory system operates on the basis of cue-based retrieval (McElree, 2000; McElree, Foraker & Dyer, 2003; Lewis & Vasishth, 2005; Van Dyke & McElree, 2006; Martin & McElree, 2009). Here, we will

assume a cue-based retrieval system as outlined in detail by Lewis and Vasishth (2005), in which linguistic items are encoded in memory as bundles of features and are content-addressable based on the features they contain. Each item stored in memory is associated with a certain level of activation. When a comprehender encounters a retrieval cue in the input, this triggers a search for a target containing a matching feature. Due to the content-addressable nature of the system, the search proceeds in a parallel rather than serial fashion (Martin & McElree, 2009). Items with a matching feature receive a boost of activation from the retrieval cue and the item with the highest activation level is retrieved from memory.

While this model gives us an outline of the process underlying memory retrieval in language comprehension, it does not specify whether the retrieval cues are as abstract as the terms in which a dependency is stated in the grammar. In the grammar, commonly dependencies like subject-verb agreement respond to very general features, such as [plural], and not more specific categories, such as *suffixal plural* or *ablauting plural*, or even particular items, such as ‘*ducks*’ or ‘*geese*’. Therefore the memory processes used to establish these dependencies might be equally abstract, displaying no sensitivity to how, specifically, the relevant general feature is introduced or signaled. Alternatively, the way a feature is introduced, its *vehicle*, might have downstream effects on its encoding or retrieval in memory. Here, we use the phenomenon of subject-verb agreement attraction in comprehension to explore this question.

### *Subject-verb agreement attraction in comprehension*

In agreement attraction in comprehension, a subject-verb agreement violation is erroneously perceived to be grammatical in the presence of a non-subject that matches in number. For

example, comprehenders are much less likely to notice the agreement violation in a sentence like *'The key to the cabinets are rusty'*, which contains the structurally inaccessible plural noun *'cabinets'*, than in the same sentence without this plural non-subject. The facilitative impact of a number-matching non-subject can be accounted for very naturally by a cue-based retrieval model (Wagers, Lau & Phillips, 2009). Subject-verb agreement is a dependency, in which the syntactic number of the verb has to match the syntactic number of the subject. In order to check this, the subject has to be retrieved from memory. In the cue-based memory retrieval system assumed here, the verb provides a number cue (e.g. [plural]) as well as a structural cue (e.g. [subject]). When one of the items from memory has features that match both the cues, it is highly likely to be retrieved. Note that when there is a number-matching non-subject present, this also receives an activation boost from the number retrieval cue. However, in a grammatical sentence, the features of the subject are a perfect match for the retrieval cues on the verb: it fulfills both the structural cue of being the subject and its number feature matches the number cue, and thus it is retrieved as the appropriate target without any issues. In contrast, in ungrammatical sentences in which the subject does not match the verb in number, a number-matching non-subject (attractor) can be erroneously retrieved in a phenomenon called facilitative similarity-based interference. In this case, the subject does not receive a boost in activation from the number cue and its activation level is only raised by the structural cue, while the attractor noun in turn receives a boost in activation from the number cue. In some cases, this leads to the misretrieval of the attractor instead of the actual target, which results in an amelioration of the processing difficulty associated with agreement violations. Although agreement attraction is an example of cue-based retrieval "gone wrong", it has for this very reason served as a useful test case for investigating the architecture of the memory system.

We note that agreement attraction was first observed in production (Bock & Miller, 1991) and that the mechanisms that have been proposed to explain this phenomenon are quite different from the cue-based retrieval model we assume here for comprehension. The production accounts have focused on the misencoding of the subject number due to the presence of the attractor (Eberhard, Cutting & Bock, 2005). While such misencoding models have also sometimes been proposed for comprehension (Pearlmutter, Garnsey & Bock, 1999), they do not capture the comprehension data as well as cue-based retrieval models, since unlike cue-based retrieval models, they predict that grammatical sentences should sometimes be perceived as ungrammatical in the presence of a plural attractor (*'The key to the cabinets is...'*), which does not seem to be the case (Wagers et al., 2009; Tucker et al., 2015; Lago, Shalom, Sigman, Lau & Phillips, 2015; but cf. Pearlmutter et al., 1999). However, as it is less clear whether production requires the same kind of cue-based memory retrieval (cf. Badecker & Lewis, 2007), it may well be the case that the mechanisms underlying attraction effects in comprehension and production are different (Tanner, Nicol & Brehm, 2014; Acuna-Farina, 2012).

Investigating subject-verb agreement attraction in comprehension provides an opportunity to address the question of whether the memory mechanisms employed in processing dependencies requiring retrieval are as abstract as the very general features in terms of which these dependencies are specified in the grammar. Subject-verb agreement is a syntactic dependency: subject and verb are syntactic categories, not phonological, morphological or semantic categories. However, the dependency involves a syntactic feature, [number], which correlates with morphological and semantic properties, if only imperfectly. For example, *'the tree'* is



syntactically singular, in triggering singular agreement, but also morphologically singular, in lacking a plural affix, and semantically singular, in representing its referent as a single tree. Crucially, however, these several properties are dissociable. Noun phrases headed by a collective noun, such as '*fleet*', are both syntactically and morphologically singular, but semantically plural, in representing their referent as a plurality of like objects. Noun phrases like '*the sheep*' or '*the deer*' can function as syntactically and semantically plural, despite any audible morpheme to mark this. And finally, several kinds of noun phrases are plural in syntax and morphology, but not plural in semantics. These include phrases headed by *pluralia tantum*, such as '*the scissors*'; those with the numeral '*one-point-zero*' ('*one-point-zero children*'); and those with the determiners '*no*' ('*no children*') or '*zero*' ('*zero grams*'). For errors of agreement attraction in language production, these properties have been partially teased apart: production errors are sensitive to syntactic number, but not semantic number or morphophonological form (Bock & Eberhard, 1993). Here we aim to use a parallel approach to determine whether the number retrieval cue in comprehension is as abstract as the features in terms of which the agreement dependency is specified in the grammar.

Recent research suggests that agreement attraction effects in comprehension depend at least partially on the way in which the syntactic plural feature is introduced, i.e. on its vehicle. A study by Tucker et al. (2015) that looked at agreement attraction in Arabic found that rates of attraction depend on the plural-formation type of the attractor. Arabic has two different plural formation strategies. For suffixation plurals, a plural suffix is added to the singular, similar to the formation of the English plural by adding the suffix '-s'. But for ablauting plurals the plural form of the noun is formed by internal vowel change. Tucker et al. found that when the plural of the attractor

was formed by suffixation, agreement attraction effects were observable in the reading times, but that with ablauting plurals in attractor position this effect was greatly reduced or absent. They argue that this suggests that the retrieval cue may be specified in terms of form rather than in terms of syntactic number.

In the present study, we compare agreement attraction with plurals formed by suffixation (*‘the cats’*) with attraction from those formed by coordination (*‘the cat and the dog’*). In English, these are both syntactically plural,<sup>1</sup> since they both trigger plural agreement<sup>2</sup>. However, importantly, only the suffixal plural is an *unequivocal* sign of syntactic plurality, in this particular sense: any occurrence of the plural suffix is within a plural noun phrase, while this is not the case with *‘and’*. For example, we find *‘and’* within singular noun phrases such as *‘my wife and confidante’* or *‘my cute and useful husband’*<sup>3</sup>. Moreover, the same word occurs between phrases of several other categories – adjective phrases, prepositional phrases, clauses – and in these cases it does not specifically mark plurality (McCloskey, 1991). Thus, while conjoined noun phrases are syntactically plural, the vehicle signaling this (*‘and’*) plays this role only by virtue of its syntactic position, between two noun phrases, and is not, in our terms, an unequivocal signal of syntactic plurality. While this distinction makes no difference in the

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<sup>1</sup> Since we are interested in whether the number retrieval cue in subject-verb agreement targets a feature as abstract as the one in terms of which the dependency is stated in the grammar (syntactic number), we only used conjoined singulars but not disjunctions. The data on what kind of agreement disjunctions like *‘the boy or the girl’* take is much less clear (Haskell & MacDonald, 2005) and it would therefore be difficult to draw any conclusions based on presence or absence of attraction effects with this type of attractor.

<sup>2</sup> In some languages, subjects with conjoined noun phrases show partial agreement, in which the verb agrees with either the first or the second conjunct (see for example Marusic, Nevins & Bedecker, 2012; Benmamoun, Bhatia & Polinsky, 2009).

<sup>3</sup> Perhaps this indicates a lexical ambiguity: maybe there are two words pronounced *‘and’*, and only one of them occurs only within plural noun phrases (King & Dalrymple 2004). Even so, we would then still like to say that conjunction is at least *superficially equivocal*, since its homophones have similar functions, syntactically and semantically. The affixal *‘-s’* might be considered ambiguous too, as between the possessive clitic and the plural affix; but it is not even superficially equivocal, since these two homophones have very different functions.

grammar, it allows us to investigate whether the retrieval cue employed in subject-verb agreement is responsive to features as abstracts as [plural], or if it targets only certain exponents of the abstract category, for instance the ones that are unequivocal correlates of syntactic plurality.

## **Experiment 1**

The goal of the set of experiments we report here was to determine whether in the computation of subject-verb agreement in comprehension, the number retrieval cue on the verb targets an abstract category, [plural], in terms of which the agreement dependency is defined in the grammar, or whether the cue is more specific, targeting only morphological correlates that are unequivocal signals of syntactic plurality. In Experiment 1 we used self-paced reading to examine whether agreement attraction in comprehension can occur even if the attractor does not contain the plural suffix ‘-s’, which is an unequivocal signal. If agreement attraction in comprehension is primarily form-driven and the number retrieval cue on the verb targets unequivocal morphological correlates of syntactic plurality in memory rather than the abstract category itself, conjoined singular noun phrases like ‘*the husband and the wife*’ should not cause agreement attraction, since they lack an unequivocal morphological correlate of syntactic plurality.

We note that conjoined singular noun phrases are certainly syntactically plural in English, since they require plural agreement on the verb when they occupy subject position (‘*The husband and the wife were/\*was next in line*’). The fact that the comprehension of such simple sentences does

not appear disrupted might already seem to be evidence that the number cue used for retrieval in agreement computation is not limited to probing for plural ‘-s’, an unequivocal morphological correlate of syntactic number, the abstract category in terms of which this dependency is defined grammatically. However, it is important to distinguish between the process of retrieving items from memory and the process of checking agreement. In two-stage models of agreement attraction, verb number is predicted upon encountering the subject, and cue-based retrieval occurs only in mismatch cases where the prediction is violated (Wagers et al., 2009; Tanner et al. 2014). In these models, abstract syntactic number would certainly be used to generate the prediction, but might or might not be the target of the error-driven cue-based retrieval.

### *Participants*

42 members of the University of Maryland community participated in this experiment for course credit or monetary compensation. The data from two additional participants was excluded due to low accuracy on the comprehension questions (below 80%). All participants were native speakers of American English and provided informed consent. None of the participants took part in more than one of the experiments presented here.

### *Materials and Design*

The materials consisted of 36 experimental item sets in a 2x3 design, which crossed the factors grammaticality (grammatical/ungrammatical) and attractor number (singular/plural/conjoined), resulting in six conditions per item. The subject always consisted of a singular head noun followed by a prepositional modifier containing the attractor. Since the head noun was always singular, the verb, which was a form of copular or auxiliary *be*, was in its singular form in the

grammatical conditions and in its plural form in the ungrammatical conditions. Attractor type was manipulated by using either a singular noun, a suffixal plural noun, or conjoined singular noun phrases, as illustrated in (1).

The items were distributed across six lists in a Latin Square design, so that each participant only saw one condition per item and six items per condition. In addition to the experimental items, the materials also included 134 filler items, 102 of which belonged to four separate manipulations that are not reported here. None of these were related to agreement processing and all filler items were grammatical, meaning that 10.6% of the items were ungrammatical in total.

(1)

- a. The slogan about *the husband* **was** designed to get attention.
- b. The slogan about *the husbands* **was** designed to get attention.
- c. The slogan about *the husband and the wife* **was** designed to get attention.
- d. The slogan about *the husband* **were** designed to get attention.
- e. The slogan about *the husbands* **were** designed to get attention.
- f. The slogan about *the husband and the wife* **were** designed to get attention.

### *Procedure*

The items were presented word-by-word in a self-paced moving window paradigm (Just, Carpenter & Woolley, 1982) using Linger software (Doug Rhode, MIT) on a desktop computer. At the beginning of each trial a series of dashes appeared on the screen, masking the words of the sentence. Participants had to press the space bar to reveal each word, at which time the previous

word was re-masked by a dash. Consequently, only one word at a time was visible and it was not possible for participants to re-read words that had already been re-masked. After the end of each sentence, a comprehension question appeared on the screen in full and participants had to press the ‘f’ key to answer ‘yes’ and the ‘j’ key to answer ‘no’. Onscreen feedback was provided only when the response was incorrect. Participants were instructed to read as naturally as possible and to answer the comprehension questions as quickly and accurately as possible. Items were presented in three blocks, and the order of presentation was randomized for each participant. Before the beginning of the experiment, participants completed five practice items to familiarize themselves with the procedure.

### *Analysis*

The regions of analysis consisted of single words and included the verb region and the two words following the critical verb (spillover regions). Reading times that exceeded a threshold of 2.5 standard deviations by region and participant were excluded from the analysis (Ratcliff, 1993), resulting in the exclusion of 3.5% of trials in the verb region, 3.8% of trials in the region one word after the verb, and 3.7% in the region two words after the verb. We analysed RTs with the *lme4* package for linear mixed effects models (Bates, Maechler, Bolker & Walker, 2015) in the R computing environment (R Development Core Team, 2016), using a model that included grammaticality and attractor type and their interaction as fixed effects. Each of the contrasts was coded with treatment coding, taking the grammatical singular attractor condition as baseline.

Following Barr, Levy, Scheepers & Tily (2013), we initially fitted a model with the maximal random effects structure, which failed to converge and was then progressively simplified until

convergence was reached. We report results from the model with the maximal random effects structure that converged for all three regions of analysis in both of the self-paced reading experiments reported here (Experiment 1 and Experiment 4). The final model included by-subject and by-item random intercepts, by-subject random slopes for attractor number, and by-item random slopes for grammaticality.

The current version of the lme4 package (version 1.1-11) no longer implements the calculation of p-values using Markov Chain Monte Carlo (MCMC) sampling, which has previously been recommended for deriving p-values from linear mixed effects models (Baayen, Davidson & Bates, 2008). Instead, following Barr et al. (2013), we evaluate the significance of the effects of grammaticality, attractor type, and their overall interaction by comparing models using likelihood ratio tests. However, since the main question of interest here is whether conjoined singular attractors cause agreement attraction effects compared to singular attractors, we also report the results from the treatment coded model, which allows us to look at this interaction. For this, we treat the t-statistic as a z-statistic, where a t-statistic with an absolute value larger than 2 suggests significance at the .05 level.

## *Results*

### *Comprehension Accuracy*

Mean comprehension accuracy for the experimental items was 94.1%. The mean accuracy for each of the conditions ranged between 91.7% to 95.8%, indicating that participants were paying

attention during the experiment. Two participants were excluded from all analyses due to a comprehension accuracy rate for the experimental items below 80%.

### *Self-paced reading*

The region-by-region average RTs of Experiment 1 are plotted in Figure 1 and the means for each condition in the verb and spillover regions are given in Table 1. The results from the mixed effects model for the verb region and the two spillover regions are presented in Table 2 to 4, with negative values indicating a decrease in RTs. For the factor grammaticality, the grammatical condition was used as the baseline and for the factor attractor type, the singular attractor was used as the baseline.

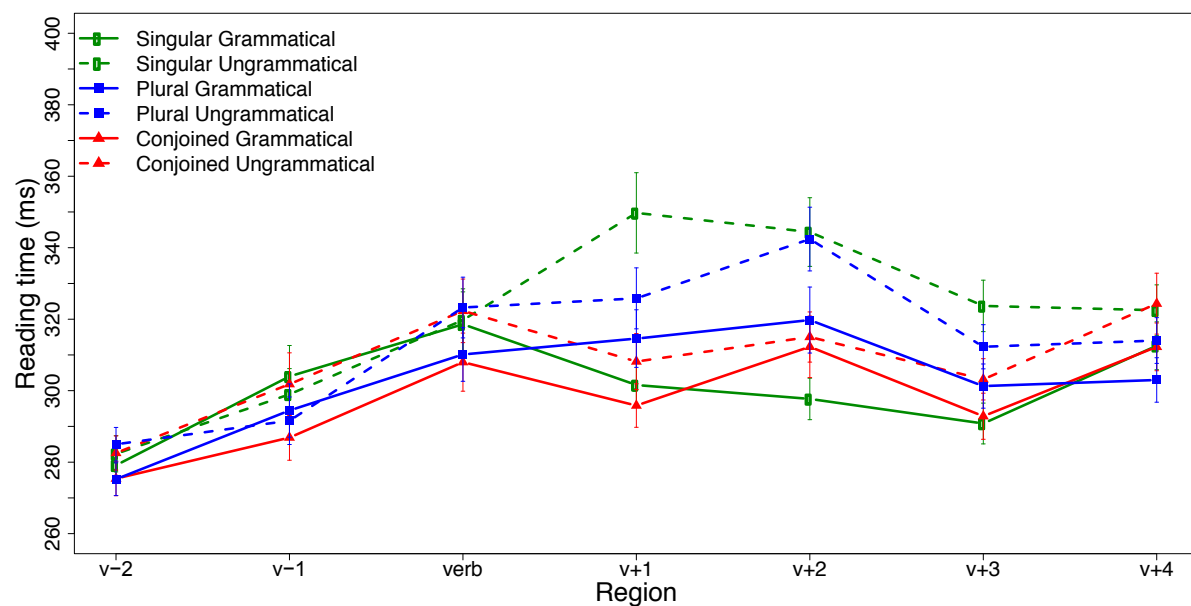


Figure 1: Region-by-region average RTs in Experiment 1, error bars indicate standard error of the mean.



	Singular, grammatical	Singular, ungrammatical	Conjoined, grammatical	Conjoined, ungrammatical	Plural, grammatical	Plural, ungrammatical
Verb	318.6 (9.1)	319.7 (8.8)	308 (8.1)	322.3 (8.9)	310.1 (7.5)	323.3 (8.5)
Verb+1	301.6 (6.2)	349.8 (11.2)	295.8 (6.1)	308.2 (7.8)	314.6 (8.1)	325.8 (8.5)
Verb+2	297.7 (5.8)	344.4 (9.6)	312.3 (8.6)	315.0 (7.0)	319.8 (9.2)	342.4 (8.9)

Table 1: Mean reading times per condition for regions of interest in Experiment 1 (standard error of the mean in parentheses)

	Estimate	Std. Error	t-value
Intercept	318.1	13.7	23.14
Grammaticality	1.8	10.4	0.17
Attr: Conjoined	-9.7	10.4	-0.93
Attr: Plural	-7.9	10.4	-0.76
Gram x Attr Conjoined	13.0	14.5	0.90
Gram x Attr Plural	11.3	14.5	0.78

Table 2: Results of linear mixed effects model for the verb region in Experiment 1

	Estimate	Std. Error	t-value
Intercept	301.9	12.1	25.05
Grammaticality	46.7	10.4	4.50
Attr: Conjoined	-6.4	10.0	-0.65
Attr: Plural	12.3	9.8	1.26
Gram x Attr Conjoined	-34.3	14.1	-2.44
Gram x Attr Plural	-33.9	14.0	-2.41

Table 3: Results of linear mixed effects model in first spillover (verb+1) region in Experiment 1

	Estimate	Std. Error	t-value
Intercept	296.9	11.1	26.67
Grammaticality	46.6	10.8	4.33
Attr: Conjoined	15.8	10.5	1.50
Attr: Plural	23.8	10.7	2.22
Gram x Attr Conjoined	-43.2	14.8	-2.92
Gram x Attr Plural	-24.8	14.7	-1.68

Table 4: Results of linear mixed effects model in second spillover (verb+2) region in Experiment

1

The likelihood ratio test showed no significant effects of grammaticality, attractor number, or their interaction in the verb region. In the first spillover region after the verb, there was a significant main effect of grammaticality ( $\chi^2(3, N = 42) = 19.309, p < 0.001$ ), a significant main

effect of attractor number ( $\chi^2(4, N = 42) = 17.926, p < 0.01$ ), and a significant overall interaction between grammaticality and attractor number ( $\chi^2(2, N = 42) = 7.7952, p < 0.05$ ). All of these effects remained significant in the second spillover region two words after the verb (grammaticality:  $\chi^2(3, N = 42) = 19.665, p < 0.001$ ; attractor number:  $\chi^2(4, N = 42) = 12.912, p < 0.05$ ; interaction between grammaticality and attractor number:  $\chi^2(2, N = 42) = 8.5739, p < 0.05$ ).

The question of interest in this experiment is whether conjoined attractors cause agreement attraction, i.e. a reduction in the disruption caused by a subject-verb agreement violation in comparison to singular attractors. Although the overall interaction between grammaticality and attractor number is significant in both spill-over regions, to determine the impact of suffixal plural vs. conjoined attractors separately we have to examine the results from the treatment coded linear mixed effects model, which separately compares the conjoined attractor and the suffixal plural attractor to the baseline singular attractor. As expected, there is a standard attraction effect with suffixal plural attractors: the interaction between grammaticality and attractor number for the suffixal plural attractor is significant in the immediate spill-over region ( $t = -2.41$ ), which indicates that the difference in RT between the grammatical and ungrammatical conditions in this region was significantly smaller with suffixal plural attractors (grammaticality effect = 11.2ms) than with singular attractors (grammaticality effect = 48.2ms). This interaction remains marginally significant in the second spill-over region ( $t = -1.683$ ), with a grammaticality effect of 22.6ms for suffixal plural attractors and 46.7ms for singular attractors. The conjoined attractor also led to a significant reduction in the grammaticality effect in the first spill-over region ( $t = -2.441$ ; grammaticality effect singular attractor = 48.2ms; conjoined attractor = 12.4ms) and the second spill-over region ( $t = -2.923$ ; grammaticality effect singular

attractor = 46.7ms; conjoined attractor = 2.7ms). This indicates that in both spill-over regions the difference in RT between the grammatical and ungrammatical conditions was significantly reduced in the presence of conjoined singular noun phrases in attractor position.

### *Discussion*

The results of Experiment 1 demonstrate that conjoined singular noun phrases of the form *determiner-noun-and-determiner-noun* cause agreement attraction effects when they occur as part of the PP-modifier of a singular subject head noun in a sentence with a subject-verb agreement violation. As expected, Experiment 1 also replicates previous results regarding agreement attraction in comprehension with suffixal plural attractors. These findings indicate that it is not necessary for a potential attractor to contain an unequivocal morphological correlate of syntactic plurality to cause facilitative similarity-based interference. This suggests that the number retrieval cue in subject-verb agreement processing does not specifically target the plural suffix ‘-s’, and that conjoined singular noun phrases are targeted equally. Therefore, the number retrieval cue either targets a disjunctive list of items (‘-s’, ‘and’, ...), or an abstract feature shared by all exponents of syntactic plurality; we return to this question in Experiments 4-6.

In previous work, agreement attraction in comprehension has been illustrated by both reduced reading times in ungrammatical sentences with a plural attractor in self-paced reading *and* a greater number of ‘acceptable’ responses for ungrammatical sentences with a plural attractor in speeded acceptability judgment (Wagers et al., 2009). In order to confirm that the reduced reading times in the conjoined attractor sentences really correspond to the failure to recognize the

agreement mismatch, we conducted a speeded acceptability judgment task with the same materials in Experiment 2.

We also note that while these results suggest that the number retrieval cue in agreement computation might be as abstract as the terms in which agreement is defined in the grammar, an unintended ambiguity in our experimental materials allows an alternative explanation. We intended strings like “*the slogan about the husband and the wife*” to be parsed as singular, with ‘*and*’ embedded in the object of the preposition: “[ the slogan about [ the husband *and* the wife ]]”, but participants could have parsed them differently, with ‘*and*’ unembedded, in a way that makes them plural: “[[ the slogan about the husband ] *and* [ the wife ]]”. In that case the plural form of the verb would have been the grammatical choice, and the RT decrease in the verb+1 region we observe for conjoined attractors compared to singular attractors would not be an indication of agreement attraction. Although this parse seems intuitively unlikely given the factors of syntactic and semantic parallelism in the current materials (e.g. [*The slogan about the husband*] *and* [*the wife*] feels quite awkward), we address this issue directly in Experiment 3, which uses conjoined singular nouns of the form *determiner-noun-and-noun*.

## **Experiment 2**

The results of Experiment 1 show that the presence of an attractor whose plurality is introduced by a vehicle that is not a perfect correlate of syntactic plurality leads to facilitated online processing of subject-verb agreement violations. Previous research has demonstrated that the

presence of a plural attractor not only mitigates processing difficulties observed in online measures, but that this effect is also reflected in the rate of acceptance of ungrammatical sentences (Wagers et al., 2009). Consequently, the aim of Experiment 2 was to determine whether the attraction effect that was found in Experiment 1 can also be detected in an acceptability judgment task. If the processing facilitation observed with conjoined singulars in Experiment 1 is the result of the same mechanism that causes attraction effects with suffixal plural attractors, we expect them to also lead to an increased rate of acceptance of ungrammatical sentences with conjoined singular attractors in an end-of-sentence acceptability judgment task.

### *Participants*

30 participants were recruited via the Amazon MechanicalTurk platform and received \$3 for completing the experiment. All participants were native speakers of American English and had passed a native speaker proficiency test. Data from 4 of the participants was excluded because their acceptance rate for the ungrammatical filler items was above 40%. None of the subjects participated in more than one of the acceptability judgment experiments reported here.

### *Materials and Design*

To ensure that the results could be easily compared to the results from the self-paced reading experiment, the experimental items were identical to those used in Experiment 1. In addition to the experimental items, we included 36 grammatical and 36 ungrammatical filler items, plus 8 control items that specifically instructed participants to choose either ‘yes’ or ‘no’ as the answer in order to confirm that participants were maintaining attention to the task. The filler items were a subset of the fillers used in Experiment 1 and half of them were edited to achieve a ratio of 1:1

of grammatical to ungrammatical items (excluding the 8 control items). The experimental items were distributed across 6 lists in a Latin Square design, ensuring that each participant saw each item in only one condition. The fillers and control items were identical across lists.

### *Procedure*

The items were displayed word by word in the center of the screen at a rate of 400ms per word using IBEX software (Drummond, 2016). The last word of each sentence was followed by a response screen prompting participants to judge whether the sentence they had just been presented with was acceptable or not by pressing the 'f'-key for 'yes' and the 'j'-key for 'no'. A response had to be made within 2000ms or the display would time out and a message would be displayed telling the participant that their response was too slow. Before the start of the experiment, participants completed five practice items to familiarize them with the procedure.

### *Analysis*

Following Jaeger (2008), we analyzed the rate of acceptance for each of the six experimental conditions using a mixed logit model with by-subject and by-item random intercepts, which was the maximal random effects structure with which the model still converged for all acceptability judgment experiments reported here. The model used treatment coding with the singular as the baseline for attractor number and grammatical as the baseline for grammaticality. Although lme4 provides p-values for mixed logit models, we also report the results from model comparisons with likelihood ratio tests to be consistent across experiments.

### *Results*

The proportion of ‘yes’ judgments for each of the experimental conditions in Experiment 2 and the difference in acceptance rate for grammatical and ungrammatical sentences for each attractor type is plotted in Figure 2. Likelihood ratio tests show that there was a main effect of grammaticality ( $\chi^2(3, N = 26) = 549.25, p < 0.001$ ), a main effect of attractor number ( $\chi^2(4, N = 26) = 93.167, p < 0.001$ ), and a significant overall interaction between grammaticality and attractor number ( $\chi^2(2, N = 26) = 38.471, p < 0.001$ ). The results from the treatment coded mixed logit model are presented in Table 5. The significant interaction between grammaticality and suffixal plural attractor ( $p < 0.01$ ) reflects the expected agreement attraction effect in the presence of a suffixal plural attractor compared to a singular attractor: the difference in acceptance rates for the grammatical and ungrammatical conditions (grammaticality effect) was  $88.1 \pm 2.5\%$  for singular attractors compared to a much reduced difference of  $61.5 \pm 6\%$  with suffixal plural attractors. The same pattern holds for conjoined attractors compared to singular attractors: there was a significant interaction between grammaticality and attractor number ( $p < 0.001$ ), with participants more likely to accept ungrammatical sentences in the presence of a conjoined attractor (conjoined grammatical – ungrammatical:  $43.2 \pm 6.6\%$ ; singular grammatical – ungrammatical:  $88.1 \pm 2.5\%$ ). Although the attraction effect was numerically larger for conjoined attractors than suffixal plural attractors, we could not conduct a statistical test of this comparison because it is not orthogonal from the other two comparisons of interest.



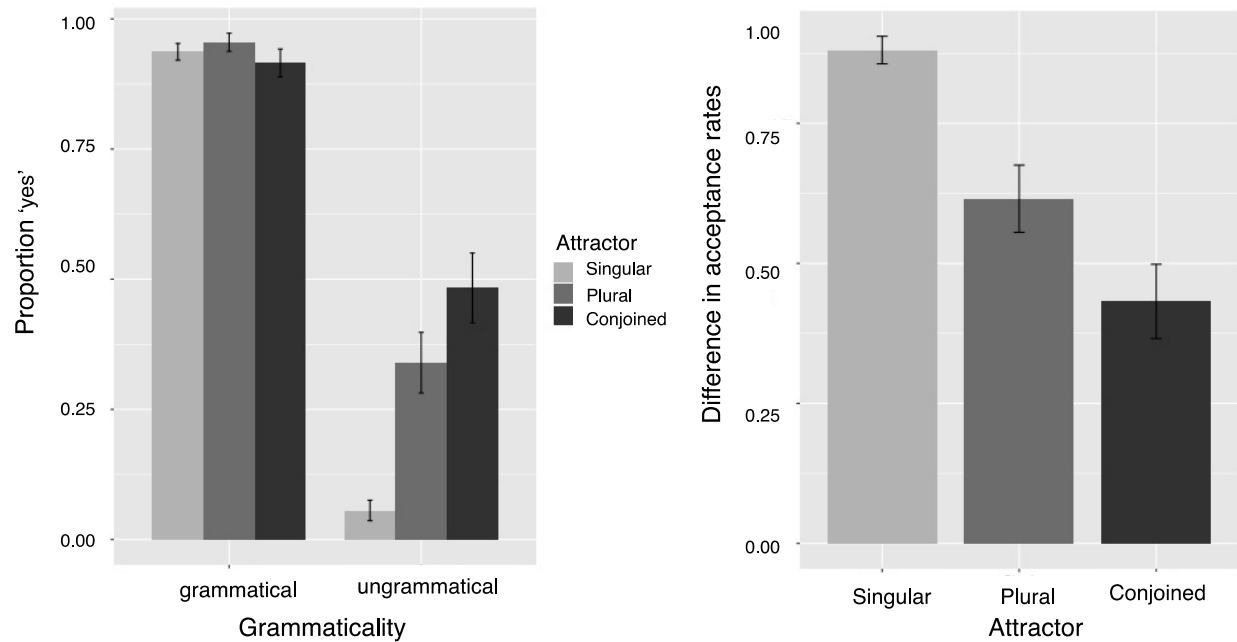


Figure 2: Acceptance rates across conditions and difference in acceptance rates for each attractor type in Experiment 2

	Estimate	Std. Error	z-value	p-value
Intercept	3.4	0.5	7.48	< 0.001
Grammaticality	-6.7	0.6	-11.43	< 0.001
Attr: Conjoined	-0.7	0.5	-1.33	0.19
Attr: Plural	0.2	0.5	0.36	0.72
Gram x Attr	3.8	0.7	5.87	< 0.001
Conjoined				
Gram x Attr Plural	2.2	0.7	3.19	0.001

Table 5: Results of mixed logit model in Experiment 2

## *Discussion*

The results of Experiment 2 are consistent with the self-paced reading results from Experiment 1. As expected, we found the standard agreement attraction effect with suffixal plural attractors: participants were more likely to accept ungrammatical sentences with a subject-verb agreement violation in the presence of a plural attractor formed by suffixation, which were judged acceptable 34% of the time, compared to only 5% in the presence of a singular attractor. Importantly, ungrammatical sentences with conjoined singular attractors were judged acceptable 48% of the time, meaning they were also more likely to be accepted than ungrammatical sentences with singular attractors. This corroborates the results of Experiment 1 and indicates that the reduced slow-down for ungrammatical sentences with conjoined singular noun phrases as the attractor in the self-paced reading task reflects reduced detection of the subject-verb agreement mismatch, just as is observed for suffixal plural attractors. Together, the findings from the self-paced reading task in Experiment 1 and the end-of-sentence judgment task in Experiment 2 suggest that the retrieval process that supports agreement computation in comprehension targets something more general than the plural suffix ‘-s’, either a disjunctive list or an abstract feature. Experiment 3 was designed to rule out an alternative explanation for these results based on the coordination ambiguity.

Experiment 2 used the same experimental materials as Experiment 1, which means that there was still an unintended ambiguity in the sentences with the conjoined singular noun phrases: it is possible, if unlikely, that participants parsed them as [*subject head noun* [*preposition* [*determiner noun*]]] and [*determiner noun*] (*[The slogan about the husband] and [the wife]*), rather than [*subject head-noun* [*preposition* [*determiner noun and determiner noun*]]] (*The*

*slogan about [the husband and the wife]*), in which case the plural form of the verb would have been grammatical. We address this issue in Experiment 3, which avoids this ambiguity by using conjoined singular noun phrases of the form *determiner-noun-and-noun*.

### **Experiment 3**

The aim of Experiment 3 was to ensure that the results we saw with conjoined singular attractors in Experiment 1 and 2 were not due to an unintended parse of this attractor type. Although conjoined attractors demonstrated a profile very similar to suffixal plural attractors, it is possible that this profile derived from a completely different source in the conjoined case. This is because the conjoined conditions had an alternative parse which is not available in the suffixal plural attraction conditions: they could be parsed as [*subject head-noun [preposition [determiner noun]]]* and [*determiner noun*] (*[The slogan about the husband] and [the wife]*), rather than as the intended [*subject head-noun [preposition [determiner noun and determiner noun]]]* (*The slogan about [the husband and the wife]*). In that case, the plural form of the verb, which was intended to be a subject-verb agreement violation, would have been grammatical, and could drive increased acceptability and reduced reading times in the ‘mismatch’ condition.

Fortunately, in English it is possible to coordinate noun phrases without a second determiner, and this forces a parse in which the two local noun phrases are coordinated: *The slogan about the husband and wife*. If participants are still more likely to accept sentences with a singular subject and a plural verb when the conjoined singular attractor does not have a second determiner, this

could not be explained by parsing ambiguity and would support our original interpretation of Experiment 1 and 2.

### *Participants*

24 native speakers of American English were recruited via the Amazon MechanicalTurk platform and received \$3 for completing the experiment. Participants who had an acceptance rate of 40% or above for the ungrammatical filler items were excluded from all analyses, which led to the exclusion of 3 of the participants who had completed the experiment. None of the participants took part in any of the other acceptability judgment experiments reported here.

### *Materials and Design*

The experimental items were adapted from those used in Experiment 1 and 2 by removing the determiner in front of the second noun phrase in the conjoined singular attractor ('*The slogan about the husband and wife*'). Consequently, the only possible parse for the sentences with the conjoined singular attractor was [*preposition [determiner noun and noun]*], avoiding the unintended ambiguity in these items in Experiment 1 and 2. The items were not changed for any of the other conditions. The same 36 grammatical and 36 ungrammatical filler items plus 8 control items were included as in Experiment 2, and the experimental items were distributed across 6 lists in a Latin Square design.

### *Procedure and Analysis*

The procedure and analysis were identical to Experiment 2.

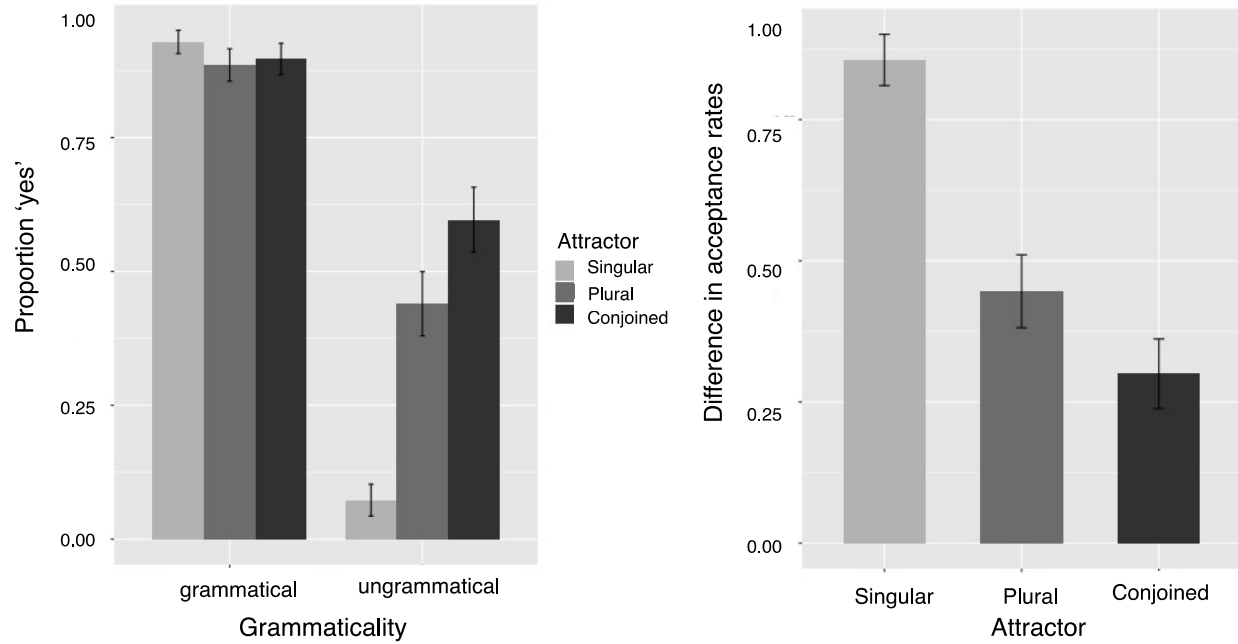


Figure 3: Acceptance rates across conditions and difference in acceptance rates for each attractor type in Experiment 3

	Estimate	Std. Error	z-value	p-value
Intercept	2.8	0.4	7.13	< 0.001
Grammaticality	-5.6	0.6	- 10.28	< 0.001
Attr: Conjoined NPs	-0.4	0.5	-0.95	0.34
Attr: Plural	-0.5	0.5	-1.16	0.25
Gram x Attr Conj. NPs	3.7	0.6	<b>5.77</b>	<b>&lt; 0.001</b>
Gram x Attr Plural	3.1	0.6	<b>4.91</b>	<b>&lt; 0.001</b>

Table 6: Results of mixed logit model for Experiment 3

## *Results*

Figure 3 shows the proportions of ‘yes’ judgments for each of the experimental conditions in Experiment 3 and the difference in acceptance rates between the grammatical and ungrammatical conditions for each attractor type. According to model comparisons with likelihood ratio tests, there was a main effect of grammaticality ( $\chi^2(3, N = 21) = 316.93, p < 0.001$ ), a main effect of attractor number ( $\chi^2(4, N = 21) = 93.094, p < 0.001$ ), and a significant interaction between grammaticality and attractor number ( $\chi^2(2, N = 21) = 43.404, p < 0.001$ ). The treatment coded mixed logit model, presented in Table 6, shows that there is a significant interaction between grammaticality and attractor number for both the suffixal plural attractor ( $p < 0.001$ ) and the conjoined attractor ( $p < 0.001$ ) compared to the baseline singular attractor. While ungrammatical sentences with a singular attractor were accepted only  $7.3 \pm 3\%$  of the time (difference between grammatical and ungrammatical:  $85.6 \pm 4.5\%$ ), this rose to  $44 \pm 6\%$  in the presence of a plural attractor (difference between grammatical and ungrammatical:  $44.6 \pm 6.5\%$ ) and to  $59.7 \pm 6.1\%$  with conjoined noun phrases as attractor (difference between grammatical and ungrammatical:  $30 \pm 6.2\%$ ).

## *Discussion*

The pattern of results in Experiment 3 is clearly consistent with the results from Experiment 1 and 2. Although no alternative parse was available for the conjoined conditions in Experiment 3, participants were still much more likely to accept ungrammatical sentences with a conjoined attractor than a singular attractor, and this effect was if anything larger than in Experiment 2. These results rule out this alternative explanation and consequently further support the idea that

an attractor that is syntactically plural can cause agreement attraction effects in comprehension, even when its plurality is not marked by the plural ‘-s’, an unequivocal signal. The retrieval cue must be more general than just a single morpheme.

There are, however, at least two options for exactly how the cue could be general. It might be an abstract feature, [plural], shared by all exponents of syntactic plurality, or it might just be a disjunctive list of items that correlate with this feature. So far, we have assumed that if conjoined singular noun phrases cause agreement attraction, it must be the abstract feature, [plural]. In Experiments 4-6, we examine the latter possibility, by considering noun phrases such as ‘*the loyal and caring husband*’ in attractor position. These include ‘*and*’ but are syntactically singular, since here the conjunction coordinates adjectives. We ask whether these too can cause errors of agreement attraction. If they do, it suggests the word ‘*and*’ has become statistically associated with syntactic plurality, to the extent that it can itself respond to the number retrieval cue triggered by the plural verb.

## **Experiment 4**

In Experiment 4, we use singular attractors with conjoined adjectives to investigate the possibility that the number retrieval cue on the verb targets correlates of syntactic plurality rather than the abstract category itself, even in cases where the correlates do not actually introduce this category. While the results of Experiments 1-3 demonstrate that retrieval is not limited to probing for an unequivocal morphological correlate of syntactic plurality (plural ‘-s’), they do

not rule out that the attraction effects we find with conjoined noun phrases is the result of retrieval targeting the word ‘*and*’, which is a correlate of syntactic plurality, although an imperfect one. Here we examine the possibility that the conjunction ‘*and*’ might be targeted in agreement computations, even though the correlation is not perfect and is not directly represented in the grammar. We can dissociate the role of abstract number and surface cues to syntactic plurality by examining the impact of singular attractors with conjoined adjectives (*the loyal and caring husband*), which contain ‘*and*’ but are not syntactically plural. If the memory processes used to establish the subject-verb agreement dependency do not just target correlates of the abstract category [plural], but are as abstract as the terms in which the dependency is stated in the grammar, this type of attractor should not cause agreement attraction effects. However, if it is morphological correlates of syntactic plurality that are targeted by the verb’s number cue in retrieval, singular attractors with conjoined adjectives should cause attraction.

### *Participants*

43 members of the University of Maryland community participated in this experiment, but the data from two participants was excluded due to a low accuracy rate (below 80%) on the comprehension questions. Participants received course credit or monetary compensation. None of the participants took part in any of the other experiments reported here.

### *Materials and Design*

The materials consisted of modified versions of the 36 experimental item sets from Experiment 1 and the same set of filler items. The 2x3 design crossed attractor type (singular with adjective/plural with adjective/singular with conjoined adjectives) with grammaticality



(grammatical/ungrammatical), resulting in six conditions per item, see (2). As in the previous experiment, the head noun of the subject was always singular, followed by a prepositional modifier containing the attractor. The attractor took the form of the definite article *the* followed by an adjective and a singular noun (singular attractor), an adjective and a plural noun (plural attractor), or a singular noun preceded by two adjectives conjoined by *and* (conjoined adjective attractor). Participants saw each experimental item in only one condition.

(2)

- a. The slogan about *the caring husband* **was** designed to get attention.
- b. The slogan about *the caring husbands* **was** designed to get attention.
- c. The slogan about *the loyal and caring husband* **was** designed to get attention.
- d. The slogan about *the caring husband* **were** designed to get attention.
- e. The slogan about *the caring husbands* **were** designed to get attention.
- f. The slogan about *the loyal and caring husband* **were** designed to get attention.

### *Procedure and Analysis*

The same self-paced reading procedure and analysis was used as in Experiment 1.

### *Results*

#### *Comprehension Accuracy*

Mean comprehension accuracy for the experimental items was 94.5%. The mean accuracy for each of the conditions ranged between 91.1% to 95.3%. Two participants were excluded from all analyses due to a comprehension accuracy rate for the experimental items below 80%.

### *Self-paced reading*

Region-by-region average RTs in Experiment 4 are plotted in Figure 4, and means for each experimental condition in the regions of interest are provided in Table 7. Table 8 to 10 present the results from the treatment coded linear mixed effects models for the verb region and the two spillover regions, negative values indicate a decrease in RT, using the singular grammatical condition as the baseline.

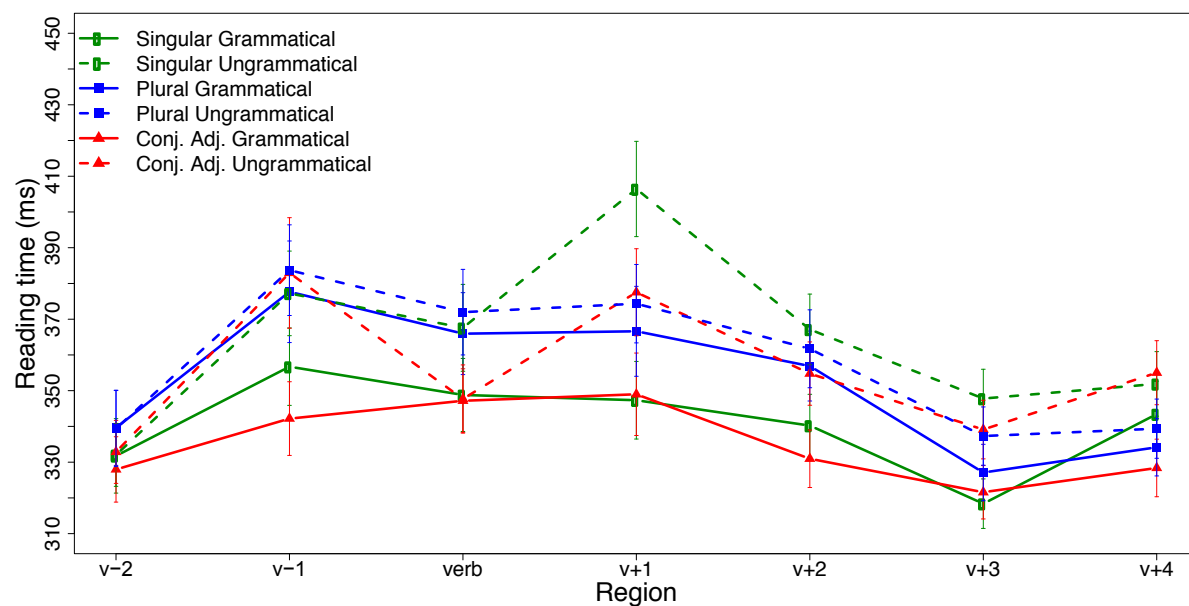


Figure 4: Region-by-region average RTs in Experiment 4, error bars indicate standard error of the mean.

	Singular, grammatical	Singular, ungrammatical	Conjoined adjectives, grammatical	Conjoined adjectives, ungrammatical	Plural, grammatical	Plural, ungrammatical
Verb	348.8 (10.2)	367.6 (12.2)	347.2 (9.0)	347.7 (9.5)	366.0 (11.5)	372.0 (12.0)
Verb+1	347.3 (10.9)	406.4 (13.3)	349.0 (11.5)	377.5 (12.2)	366.6 (12.6)	374.3 (11.0)
Verb+2	340.2 (8.8)	367.1 (9.9)	331.0 (8.0)	354.8 (8.9)	356.9 (9.8)	361.7 (10.9)

Table 7: Mean reading times per condition for regions of interest in Experiment 3 (standard error of the mean in parentheses)

	Estimate	Std. Error	t-value
Intercept	348.7	18.3	19.05
Grammaticality	19.2	12.4	1.55
Attr: Conjoined Adjectives	-1.7	12.6	-0.14
Attr: Plural	15.6	12.3	1.27
Gram x Attr Conj. Adj.	-19.4	17.3	-1.12
Gram x Attr Plural	-11.2	17.3	-0.65

Table 8: Results of linear mixed effects model for the verb region in Experiment 4

	Estimate	Std. Error	t-value
Intercept	347.1	21.1	16.47
Grammaticality	60.9	13.9	<b>4.38</b>
Attr: Conjoined Adjectives	1.3	13.7	0.09
Attr: Plural	20.6	13.4	1.54
Gram x Attr Conj. Adj.	-34.4	18.7	<b>-1.84</b>
Gram x Attr Plural	-53.0	18.8	<b>-2.83</b>

Table 9: Results of linear mixed effects model for the spillover (verb+1) region in Experiment 4

	Estimate	Std. Error	t-value
Intercept	340.4	16.6	20.51
Grammaticality	27.5	10.4	<b>2.63</b>
Attr: Conjoined Adjectives	-9.2	10.8	-0.85
Attr: Plural	17.3	10.4	<b>1.66</b>
Gram x Attr Conj. Adj.	-4.1	14.7	<b>-0.28</b>
Gram x Attr Plural	-23.5	14.7	<b>-1.60</b>

Table 10: Results of linear mixed effects model for the spillover (verb+2) region in Experiment 4

According to likelihood ratio tests, there was no significant effect of grammaticality or the interaction between grammaticality and attractor number in the verb region<sup>4</sup>. In the first spillover region, there was a significant main effect of grammaticality ( $\chi^2(3, N = 41) = 19.836, p < 0.001$ ), a significant main effect of attractor number ( $\chi^2(4, N = 41) = 10.645, p < 0.05$ ), and a significant overall interaction between grammaticality and attractor number ( $\chi^2(2, N = 41) = 8.1985, p < 0.05$ ), but only the main effect of grammaticality remains significant in the second spillover region ( $\chi^2(3, N = 41) = 11.916, p < 0.01$ ).

The treatment coded linear mixed effects model directly compares the plural attractor and the attractor with conjoined adjectives with the singular attractor as baseline, which are ultimately the comparisons we are interested in here. Consistent with the likelihood ratio tests, the results indicate that there are no significant interactions between attractor number and grammaticality in the verb region or the second spillover region, but in the first spillover region we see the expected interaction between grammaticality and plural compared to singular attractor number ( $t = -2.83$ ). As observed in prior experiments, the slow-down associated with ungrammatical sentences is greatly reduced in the presence of a plural attractor (grammaticality effect = 7.7ms) compared to a singular attractor (grammaticality effect = 59.1ms). Interestingly, in this first spillover region there is also a marginally significant interaction between grammaticality and conjoined adjectives versus singular attractors ( $t = -1.84$ ), indicating a reduced slow-down for

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<sup>4</sup> Unfortunately the model for the verb region did not converge when the attractor number factor was removed, so we were unable to conduct a likelihood ratio test evaluating the main effect of attractor number in this region. One option would be to simplify the model further (e.g. removing by-item or by-subject random slopes for one of the factors), but for consistency this would require simplifying all of the self-paced reading models in the study in the same way. Since the presence or absence of this main effect played no role in our hypotheses of interest, which were all focused on the interaction, we chose instead to omit this one likelihood ratio test. Also note that the treatment-coded model outputs in Table 8 provide complementary information, indicating that neither the plural or conjoined adjective attractors differed significantly from the singular attractor in this region.

ungrammatical sentences in the presence of a singular attractor with conjoined adjectives (grammaticality effect = 28.5ms).

### *Discussion*

These results provide intriguing but only tentative support for the hypothesis that the word ‘*and*’ is a target for retrieval cued on plural number. Singular attractors that contained the word ‘*and*’ appeared to induce a small attraction effect, reducing the slow-down associated with encountering an ungrammatical plural verb, but in contrast to the true syntactically plural conjoined attractors examined in Experiment 1, the effect of conjoined adjective attractors was smaller than the classic plural attraction effect and was only marginally significant. If this effect were reliable, however, it would suggest that an attractor that does not actually signal syntactically plurality can nonetheless cause interference in agreement computation, simply because the attractor is an imperfect correlate of syntactic plurality. In order to further investigate this issue, Experiment 5 uses the materials from Experiment 4 in an acceptability judgment task.

### **Experiment 5**

Although the results from Experiment 4 suggest that the presence of the conjunction ‘*and*’ in an attractor that is not syntactically plural might cause agreement attraction, this was only a marginally significant effect. Here, we follow up this result by using the same materials as in Experiment 4, with singular attractors with conjoined adjectives, in an acceptability judgment task. If the presence of ‘*and*’ in the attractor is sufficient to cause agreement attraction, this

should be reflected in higher acceptance rates for ungrammatical sentences in the presence of singular attractors with conjoined adjectives compared to singular attractors with only one adjective.

### *Participants*

We recruited 24 participants via Amazon's Mechanical Turk platform. All participants were native speakers of American English and received \$3 for participating in the experiment. Two of the participants were excluded from all analyses because they accepted the ungrammatical filler sentences more than 40% of the time.

### *Materials and Design*

The experimental items in Experiment 5 were identical to those used in Experiment 4, to ensure that results were easily comparable. The materials also included the same 36 grammatical and 36 ungrammatical fillers, as well as the 8 control items, used in the other acceptability judgment experiments reported here. The experimental items were distributed across 6 lists in a Latin Square design, with fillers and control items identical across lists.

### *Procedure and Analysis*

The procedure and analysis used in Experiment 5 were identical to those in Experiment 2 and 3.

### *Results*

The proportion of 'yes' judgments for all the experimental conditions and the difference in acceptance rates between grammatical and ungrammatical sentences for each attractor type is

illustrated in Figure 5. Likelihood ratio tests show that there was a main effect of grammaticality ( $\chi^2(3, N = 22) = 534.46, p < 0.001$ ), a main effect of attractor type ( $\chi^2(4, N = 22) = 30.602, p < 0.001$ ), and a significant interaction between grammaticality and attractor type ( $\chi^2(2, N = 22) = 15.517, p < 0.001$ ). Table 11 contains the results from the treatment coded mixed logit model, which shows that, as expected, the interaction between grammaticality and attractor type was significant for the plural attractor compared to the singular baseline ( $p < 0.001$ ), with ungrammatical sentences being accepted more frequently with a plural attractor ( $35.8 \pm 6.3\%$ ; grammaticality effect:  $57.3 \pm 7\%$ ) than with singular attractors ( $10.6 \pm 3.9\%$ ; grammaticality effect:  $86.4 \pm 4.2\%$ ). In our critical comparison, the interaction was also significant for singular attractors with conjoined adjectives compared to the baseline singular attractor with only one adjective ( $p < 0.05$ ). The presence of a singular attractor with conjoined adjectives made participants more likely to accept ungrammatical sentences ( $20.6 \pm 5\%$ ; grammaticality effect:  $73.3 \pm 6.4\%$ ) than when the singular attractor had only one adjective.



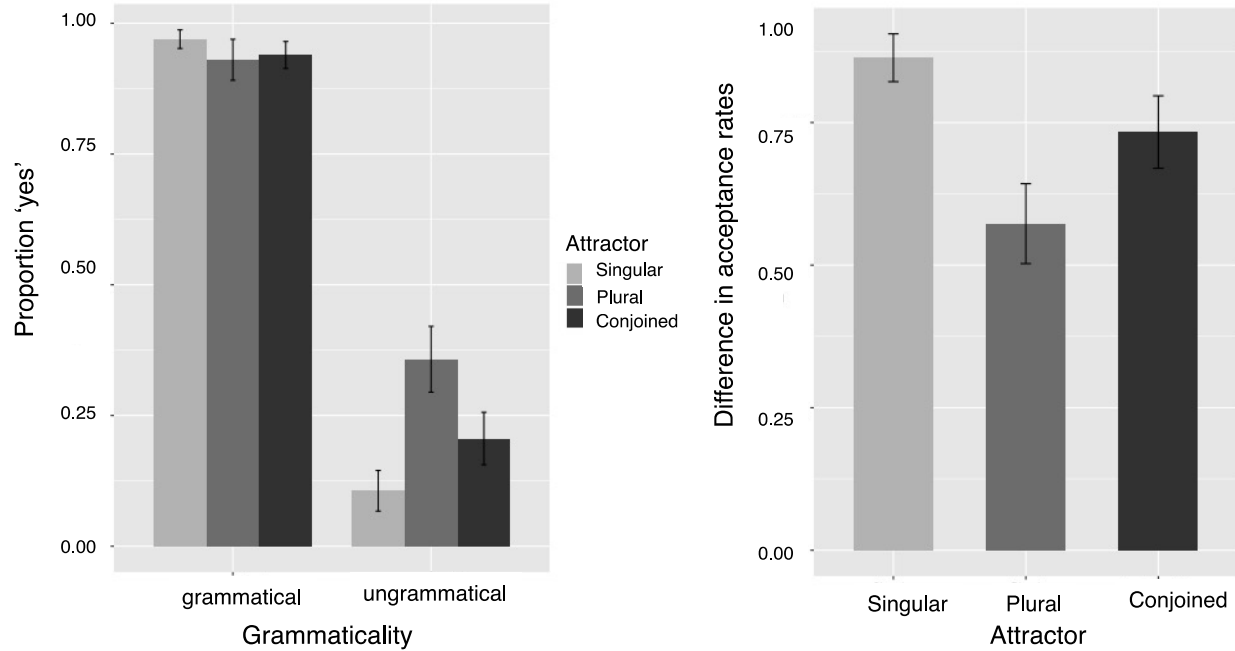


Figure 5: Acceptance rates across conditions and difference in acceptance rates for each attractor type in Experiment 5

	Estimate	Std. Error	z-value	p-value
Intercept	3.8	0.6	6.81	< 0.001
Grammaticality	-6.3	0.6	-10.05	< 0.001
Attr: Conjoined adjectives	-0.8	0.6	-1.17	0.24
Attr: Plural	-0.9	0.6	-1.47	0.14
Gram x Attr Conj. Adj.	1.6	0.7	<b>2.21</b>	<b>0.03</b>
Gram x Attr Plural	2.7	0.7	<b>3.73</b>	<b>&lt; 0.001</b>

Table 11: Results of mixed logit model in Experiment 5

## *Discussion*

The results from Experiment 5 corroborate the finding from Experiment 4 that singular attractors with conjoined adjectives result in a small agreement attraction effect, increasing the acceptability of a plural-marked verb in the context of a singular subject head noun and reducing the associated reading time disruption. It is notable that in both experiments the attraction effect was markedly smaller for singular conjoined adjective attractors than for the plural attractors, which was not the case for the conjoined noun phrase attractors examined in Experiments 1 and 2. This suggests that the attraction observed with conjoined noun phrases is not simply due to retrieval of the word ‘*and*’ as a correlate of syntactic plurality. Nevertheless, the fact that singular attractors with conjoined adjectives increase the acceptance rate of ungrammatical sentences and lead to a reduced slowdown in self-paced reading suggests that the presence of ‘*and*’ in the attractor causes some interference in agreement computation, even if the attractor is neither syntactically plural nor contains an unequivocal signal of syntactic plurality.

One potential explanation for the observed attraction effect with ‘*and*’ is that comprehenders are more likely to expect a plural noun following conjoined adjectives. If that were the case, their prediction of a plural noun, even in the absence of one in the actual input, might have caused interference in computing agreement. To rule this out, we conducted an untimed cloze task with the materials from Experiment 5. The items were cut off after the adjective/conjoined adjectives and 32 participants completed the sentences. The cloze probability of a plural noun following conjoined adjectives was only 5.6% (32 completions out of 576) and, in fact, lower than after a

single adjective, where it was 6.6% (38 completions out of 576). This indicates that comprehenders were not more likely to expect a plural noun after conjoined adjectives. Consequently, predicting a plural cannot be the source of the attraction effect observed with conjoined adjective attractors.

However, one potential confound in Experiment 5 is that in the conditions with singular attractors with conjoined adjectives the head noun of the subject is separated from the verb by two additional words in comparison to the conditions with the singular and plural attractors that include only one adjective. In Experiment 6 we address this issue by testing singular attractors with stacked adjectives (*the loyal, caring husband*), which increase the distance between the head noun and the verb and have a similar semantic representation as explicitly conjoined adjectives without including the word ‘*and*’ as a potential target for retrieval.

## **Experiment 6**

The aim of Experiment 6 was to investigate whether the apparent attraction effect observed in Experiments 5 for singular attractors with conjoined adjectives was simply due to the additional length/complexity of the attractor region rather than specifically the presence of the word ‘*and*’, which is an imperfect correlate of syntactic plurality. In Experiment 6, we adapted the materials from Experiment 5 to include a singular attractor with stacked adjectives (‘*The slogan about the loyal, caring husband*’), thereby increasing the distance between the head noun and the verb. If the increase in acceptance rate for the ungrammatical sentences with singular attractors

containing conjoined adjectives was a result of the increased distance between the head noun and the verb, then a singular attractor with stacked adjectives should lead to an increased acceptance rate for ungrammatical sentences compared to a singular attractor containing only one adjective. If the effect is rather due to the word ‘*and*’, then it should be observed in the conjoined adjective but not the stacked adjective condition.

### *Participants*

As with the other acceptability judgment experiments reported here, participants were recruited via Amazon’s Mechanical Turk platform, were all native speakers of American English and received \$3 for completing the experiment. There was a total of 24 participants, but 2 participants were excluded from all analyses because they accepted the ungrammatical filler items at a rate of 40% or above.

### *Materials and Design*

The materials were adapted from those used in Experiment 4 and 5. Instead of using a suffixal plural attractor as one of the attractor types, we included a singular attractor preceded by two stacked adjectives (‘*the loyal caring husband*’). Consequently, the three attractor types were singular attractor with single adjective (‘*the caring husband*’), singular attractor with stacked adjectives (‘*the loyal caring husband*’), and singular attractor with conjoined adjectives (‘*the loyal and caring husband*’). For some of the items, the order of the adjectives was reversed from Experiment 4 and 5 to make the stacked adjectives sound more natural, but this was kept constant across all experimental conditions. The experimental items were distributed across 6 lists in a Latin Square design, so that each participant saw each item in only one condition. Filler

items (72, ratio of 1:1 grammatical vs. ungrammatical) and control items were the same as in the other acceptability judgment experiments and were identical across lists.

### *Procedure and Analysis*

The same acceptability judgment procedure and analysis was used as in Experiment 2, 3, and 5.

### *Results*

Figure 6 plots the proportion of ‘yes’ judgments for each experimental condition and the difference in acceptance rates between grammatical and ungrammatical sentences for each attractor type. Likelihood ratio tests reveal a main effect of grammaticality ( $\chi^2(3, N = 22) = 546.77, p < 0.001$ ) and a significant interaction between grammaticality and attractor type ( $\chi^2(2, N = 22) = 7.8655, p < 0.05$ ). The results from the treatment coded mixed logit model are presented in Table 12. While there was no interaction between grammaticality and attractor type for the singular attractor with the stacked adjectives compared to the singular attractor with one adjective, this interaction was significant for the singular attractor with conjoined adjectives versus the singular attractor with one adjective ( $p < 0.05$ ). Like in Experiment 5, participants were more likely to judge ungrammatical sentences as acceptable when they contained a singular attractor with conjoined adjectives (grammaticality effect =  $66.5 \pm 5.7\%$ ) than when the singular attractor contained only one adjective (grammaticality effect =  $78.6 \pm 5.9\%$ ).

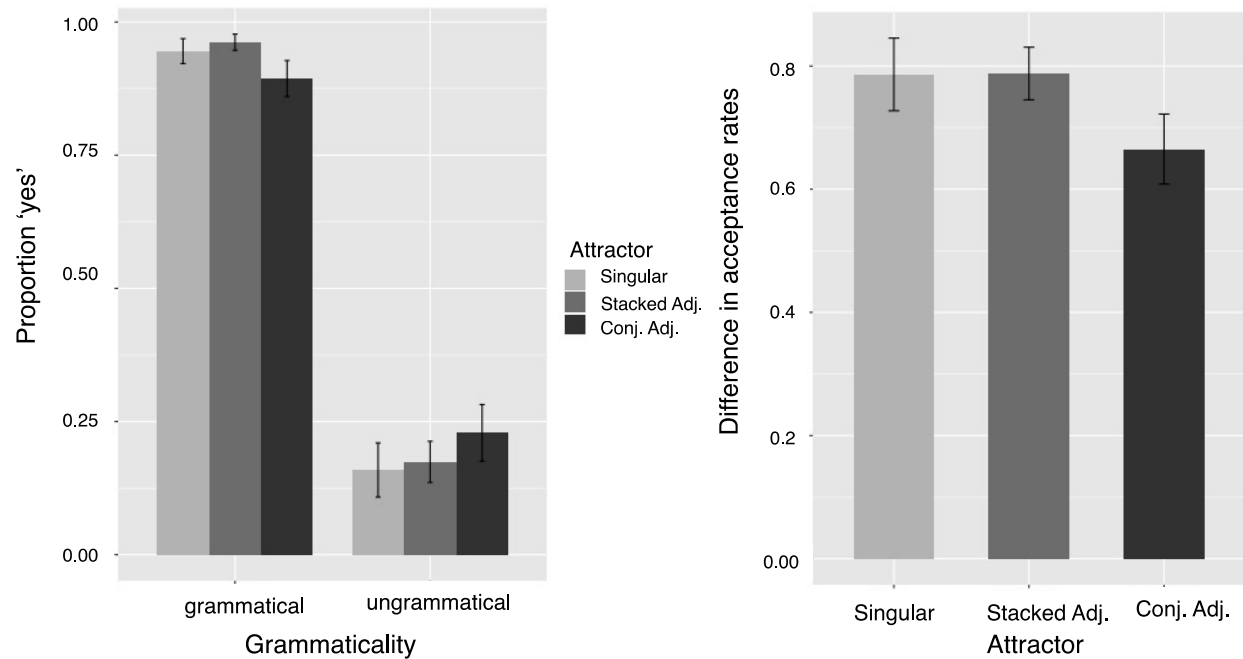


Figure 6: Acceptance rates across conditions and difference in acceptance rates for each attractor type in Experiment 6

	Estimate	Std. Error	z-value	p-value
Intercept	3.3	0.5	7.00	< 0.001
Grammaticality	-5.3	0.5	-10.11	< 0.001
Attr: conjoined adjectives	-0.8	0.5	-1.61	0.11
Attr: stacked adjectives	0.4	0.6	0.63	0.53
Gram x Attr Conj. Adj.	1.3	0.6	<b>2.19</b>	<b>0.03</b>

Gram x Attr	-0.2	0.7	-0.33	0.74
Stacked Adj.				

Table 12: Results of mixed logit model in Experiment 6

### *Discussion*

Experiment 6 replicated the finding from Experiment 5 that ungrammatical sentences are more likely to be accepted in the presence of a syntactically singular attractor with conjoined adjectives. In contrast, singular attractors with stacked adjectives did not increase the likelihood of ungrammatical sentences to be judged acceptable. This indicates that the increase in acceptance rate we see with the conjoined adjectives in this experiment and Experiment 5 is not simply due to the increased linear distance between the subject's head noun and the verb. Instead, it seems that the presence of the conjunction '*and*' results in some degree of agreement attraction when the verb is plural, even when the noun phrase it appears in is syntactically singular as in the conjoined adjective case. We return to the question of what this means for the relationship between cues and features in the memory system in the general discussion.

### **General Discussion**

The experiments reported here investigated whether the number retrieval cue on the verb used in the processing of subject-verb agreement in comprehension is as abstract as the terms in which the grammatical dependency is stated, or whether it matters how the relevant property (syntactic plurality) is introduced. The experiments that used conjoined singular noun phrases as attractors

(Exp. 1-3) demonstrated equivalent agreement attraction effects for attractors containing plural ‘-s’, which correlates perfectly with syntactic plurality, and conjoined attractors that are syntactically plural but contain only an equivocal signal of syntactic plurality, both in self-paced reading and speeded acceptability measures. Additionally, we found a small attraction effect even with syntactically singular attractors when they contained conjoined adjectives (Exp. 4-6), which was reliable in speeded acceptability and marginal in self-paced reading. This effect did not seem to be the result of a tendency of comprehenders to expect a plural noun after conjoined adjectives, or increased linear distance between the subject’s head noun and the verb (Exp. 6).

#### *The role of morphological form in memory retrieval*

The results of Experiments 1-3 suggest that the agreement computation process in comprehension targets features more abstract than only the unequivocal exponent of syntactic plurality (plural ‘-s’) during cue-based memory retrieval. We found that comprehenders showed facilitation in ungrammatical singular-subject/plural-verb sentences when a non-subject consisting of conjoined singular noun phrases served as an attractor, even though the syntactic plurality of this attractor was not introduced by an unequivocal signal. In the self-paced reading experiment, this facilitation took the form of a reduced slow-down in the verb’s spillover region, and in the speeded acceptability judgment tasks this was reflected in higher acceptance rates. In all three experiments, agreement attraction effects for conjoined singulars were numerically equivalent or larger than effects for suffixal plurals.

Of course, it is generally accepted that subject-verb agreement in the grammar of English is licensed by abstract syntactic number rather than the presence of particular morphological



correlates of this abstract category. However, given previous findings that agreement attraction in comprehension is sensitive to the attractor's plural formation strategy in Arabic (Tucker et al. 2015), it could have been the case that online processing mechanisms target only certain exponents of the abstract category. For example, in two-stage models of agreement attraction, verb number is predicted on the basis of the subject, and agreement attraction effects occur as a result of errors in a memory retrieval 'rechecking' process when the form of the verb does not match this prediction. Unequivocal morphological signals of syntactic plurality could have been the primary target of this latter memory retrieval process, but our results suggest that this is not the case.<sup>5</sup> Our results similarly indicate that syntactic number is rapidly computed for conjoined singulars, as they were able to interfere with the memory retrieval operation cued at the immediately subsequent verb.

Our finding that retrieval mechanisms for agreement computation were not sensitive to the vehicle by which syntactic plurality is introduced contrasts with the results from Tucker et al. (2015), who used a different form manipulation in Arabic. In their study, the rate of agreement attraction was modulated by the particular plural formation strategy used for the attractor (suffixation vs. ablauting). One potential explanation for this contrast is that the mechanisms underlying agreement processing might be different cross-linguistically: English and Arabic have very different number and agreement systems, which could lead to differences in processing strategies.

As we discuss further in the next section, it is also not the case that our results rule out any effects of surface form on the memory retrieval processes associated with agreement

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<sup>5</sup> Here recall footnote 3.

computations: The small agreement attraction effect we observed with singular attractors containing conjoined adjectives (*'the diligent and compassionate doctor'*) might be interpreted as an indication that the morpheme *'and'*, which is an imperfect correlate of syntactic plurality, is targeted by the verb's number retrieval cue, even if the noun phrase in which it occurs is not syntactically plural. However, conjoined adjectives led to a much smaller attraction effect than conjoined singular noun phrases or suffixal plural attractors, indicating that overt correlates of syntactic plurality are not the main target of the number retrieval cue on the verb.

### *Associative Cues*

Experiments 4-6 provided evidence that the presence of the conjunction *'and'* within the attractor caused a small interference effect even when the phrase was syntactically singular. The small agreement attraction effect with conjoined adjectives is compatible with the hypothesis that the relationship between retrieval cues and features in sentence processing is associative rather than categorical, and may not strictly follow the cue-feature relationships licensed by the grammar (Engelmann, Jaeger & Vasisht., 2016). Under this view, the relationship between cues and features is not a categorical match or mismatch; instead cues can be associated with multiple features to different extents. The association between cues and features is learned based on exposure, and while they usually reflect grammatical knowledge, over time co-occurrence patterns can lead to the association of cues with features they are not linked to in the grammar.

Engelmann et al. (2016) suggest that if two features frequently co-occur on the target item in a linguistic dependency, over time they might both become associated with the retrieval cue, even if only one of them is conceptually linked with it. For example, in the case of reciprocals in

English, the features *+c-command* and *+plural* always co-occur on the antecedent of the reciprocal. Consequently, in this dependency the plural retrieval cue becomes associated not only with the plural feature but also the c-command feature, and vice versa for the c-command retrieval cue. In the case of subject-verb agreement, while the actual target of the number retrieval cue is (syntactic) plurality, which controls agreement in the grammar, the presence of ‘*and*’ might have served as a kind of surface cue to plurality, even in the absence of a syntactically plural attractor. Although singular attractors with conjoined adjectives are not actually plural, the conjunction ‘*and*’ frequently co-occurs with syntactic plurality, so it is possible that it has become associated with the plural retrieval cue. This association would not be as strong as the association between the cue and its actual target feature, so while a singular attractor with conjoined adjectives might receive some activation from the verb’s plural retrieval cue, this would lead to the attractor being misretrieved much less frequently than a syntactically plural attractor.

#### *Semantic plurality vs. syntactic plurality in agreement computation*

While our findings indicate that an unequivocal morphological correlate of syntactic plurality (plural ‘-s’) is not required for a structurally inaccessible noun phrase to function as an attractor in subject-verb agreement processing, we acknowledge that our experiments cannot clearly distinguish between the role of syntactic and notional plurality. The conjoined singular noun phrases we used as attractors in Experiments 1-3 are not only syntactically but also notionally plural. In fact, conjoined noun phrases have been argued to be even ‘more’ plural than regular plurals in a certain sense: they introduce complex reference objects into the discourse, which are

fully specified for number, unlike plural definite descriptions, which are arguably underspecified (Patson, 2014).

Although we cannot rule out that the attraction effect we observe with the conjoined singular noun phrases is driven by the number retrieval cue targeting a semantic correlate of syntactic plurality in memory, other evidence casts some doubt on this possibility. Experiments on agreement attraction in production have used collective nouns (like ‘*the fleet*’) to examine the impact of notional number. Collectives are an interesting test case, because they take singular agreement in American English, and are therefore syntactically singular, despite (arguably) representing their referent as comprising multiple objects. In spite of this notional plurality, Bock and Eberhard (1993) found that collectives do not lead to an increase in the production of agreement errors. Although the difference in the processes underlying agreement attraction in comprehension and production means that we cannot draw definitive conclusions from these findings, in a recent self-paced reading experiment we also failed to find attraction with collective nouns in comprehension (unpublished data)<sup>6</sup>. While more work is needed, these data lead us to favor an account in which syntactic number, which licenses agreement grammatically, is also the primary feature being targeted by the online memory retrieval operations that are reflected in agreement attraction.

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<sup>6</sup> In this experiment, we manipulated the notional plurality of the collective attractor by varying the preceding sentence such that it either simply mentioned the collective as a whole or drew attention to the fact that it referred to a group consisting of multiple entities, thus emphasizing its distributive meaning (‘*The fleet was powerful and looked very impressive. / The fleet consisted of forty ships and looked very impressive. – The captain of the fleet was/were known for his battle skills.*’). Regardless of the preceding sentence, collectives did not lead to a reduction in processing difficulty in ungrammatical sentences.

## *Conclusion*

We used self-paced reading and speeded acceptability judgments to demonstrate that the vehicle by which the relevant feature that licenses the subject-verb agreement dependency in the grammar, syntactic number, is introduced, does not have an impact on whether a structurally inaccessible syntactically plural noun phrase interferes in agreement computation in comprehension. Conjoined singular NPs, which are syntactically plural but contain only an equivocal morphological signal of plurality, caused strong attraction effects, indicating that the verb's number retrieval cue is specified in more abstract terms and does not specifically target only the unequivocal exponent of the abstract feature (plural '-s'). However, we also found a much smaller attraction effect with attractors with conjoined adjectives, which are not syntactically plural and do not license plural agreement in the grammar. We hypothesize that this is because '*and*' frequently co-occurs with syntactic plurality and has therefore become weakly associated with the plural retrieval cue. Taken together, these findings suggest that the feature primarily targeted in memory retrieval operations linked to agreement processing are more abstract than a specific exponent of the abstract category syntactic number, but that due to the associative nature of cues and features, surface cues that are imperfect correlates of syntactic plurality like '*and*' can also interfere to a smaller extent.

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